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RELATIONSHIP OF THE ALBEDO OF VENUS TO WAVELENGTH IN THE ULTRAVIOLET BAND OF THE SPECTRUM

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Resume. Thirty spectrograms of Venus were obtained during the period of January-February 1963 using the slitless spectrograph at the high altitude station of the Sternberg Astronomical Institute. The star α Lyr was used as a comparison body. The relationship of the albedo of Venus to the wavelength in the $\lambda\lambda$ 4,500-3,200 Å interval was determined. It was found that the albedo of the planet decreases insignificantly with a diminution of the wavelength; this is contrary to the data provided by Kozyrev [7]. An attempt was made to determine the spherical albedo, utilizing the phase curves of Venus provided by various authors.

The purpose of this study is to study the relationship of the albedo of Venus to the wavelength in the ultraviolet region of the spectrum. Observations of Venus were made in a slitless spectrograph, the ASI-5 instrument, mounted in the Vysokogornyy Expedition of GAISh [Shternberg State Astronomic Institute] at an altitude of 3,000 m. The diameter of the main reflector in the instrument is 250 mm and the equivalent light gathering power is 1:7.5. The dispersion is 150 Å/mm at H_γ and 50 Å/mm in the 3,000 Å region.

Thirty spectrograms of Venus were obtained during a period of 7 nights in the months of January and February 1963. The star α Lyr was used as a comparison star; its energy distribution in the spectrum has been throughly studied. The spectra of Venus and α Lyr were photographed with the same exposure in 1 m on Astro-Platton plates. The brightness of Venus was reduced by three diaphragms which were placed on the tube of the instrument. Each of the diaphragms had four circular openings of similar diameter disposed symmetrically with respect to the center of the diaphragm every 90° on the circumference. The difference in diameters of the openings in each of the three diaphragms produced differing reductions in brightness intensity. This made it possible without changing the exposure time to get normal densities of blackening throughout the entire spectrum of Venus (λλ 3,200 Å - 4,500 Å). Each of the diaphragms was studied separately and it was found that the reductions in glitter were respectively $4^m \cdot 1$, $4^m \cdot 6$, and $5^m \cdot 6$.

In order to exclude the effect of light absorption by the earth's atmosphere, the spectra of Venus and α Lyr were photographed at similar zenith distances. The assumption was made that during the time which elapsed between the exposures of Venus and the comparison star no change in the coefficient of transparency had occurred. Table 1 gives the geocentric and heliocentric distances and phase angles of Venus during the period of observations.

Table 1

Date of Observation	ρ	Δ	k	Φ	r''
25. I	0.686	0.740	0.510	88°.9	12"
26. I	0.694	0.741	0.515	88 .3	12
28. I	0.709	0.742	0.525	87 .1	12
30. I	0.725	0.743	0.535	85 .9	12
8.II	0.786	0.740	0.571	81 .8	11
9.II	0.801	0.737	0.578	81 .0	10
24.II	0.913	0.745	0.643	73 .4	9

ρ -- the geocentric distance of Venus express in astronomic units,
Δ -- the heliocentric distance in astronomic units,
k -- ratio of illuminated portion of disc of Venus to entire surface of disc,
Φ -- phase angle.

The registergrams of the spectra were received at GAISh on a microphotometer of intensities. The measurements were made in 18 sectors of continuous spectrum; these were free of absorption lines.

The following is a list of wave lengths in which the intensities of the continuous spectrum were measured.

λλÅ 4530, 4350, 4210, 4130, 4015, 3935, 3900, 3790, 3750, 3650, 3610, 3560, 3500, 3460, 3400, 3350, 3290, 3225.

For each spectrum of Venus differences in monochromatic stellar magnitudes of Venus and α Lyr were obtained, following which the mean Δm_λ were computed for each night.

In order to get the distribution of energy in the Venus spectrum in absolute units we used mean energy distribution data in the spectrum of α Lyr. The data of Kharitonov [1] were compared with the spectrophotometric results of α Lyr which were obtained by Glushneva for the $\lambda\lambda$ 4,700 - 3,000 Å region of the spectrum. The results obtained by the two authors are in good agreement and differ by not more than 10% in the entire band of wavelengths studied. The averaged data for the distribution of energy in the spectrum of α Lyr are given in Table 2.

Table 2

$\lambda\lambda$	E_*	$E_\odot$	$\log p'_\lambda$	$\lambda\lambda$	E_*	$E_\odot$	$\log p'_\lambda$
4530	$6.1\cdot10^{-1}$	$2.20\cdot10^{10}$	−0.722	3650	$2.9\cdot10^{-1}$	$1.29\cdot10^{10}$	−0.760
4350	6.6	1.82	−0.655	3610	2.9	1.18	−0.774
4210	7.1	1.92	−0.688	3560	2.95	1.16	−0.800
4130	7.3	1.94	−0.720	3500	3.0	1.18	−0.821
4015	7.8	1.65	−0.652	3460	3.1	1.17	−0.809
3935	7.85	1.18	−0.631	3400	3.2	1.11	−0.775
3900	7.65	1.12	−0.658	3350	3.25	1.11	−0.778
3790	5.20	1.26	−0.685	3290	3.25	1.13	−0.800
3750	4.0	1.32	−0.744	3225	3.1	0.90	−0.842

Since no direct comparison of the spectra of Venus and the sun was made the distribution of energy in the sun's spectrum was taken from a study by Johnson [2]. The data of this distribution in the spectrum portions studied are given in Table 2.

Shown in Fig. 1 are the energy distribution curves in the spectrum of Venus in absolute units. The thin lines represent curves obtained during the separate nights of observation, and the averaged out data are shown by the solid lines with circles. For purposes of comparison on this diagram there is shown in broken line the distribution of energy in the solar spectrum expressed in arbitrary units. The distribution curves obtained on separate nights deviate from the mean curve by not more than 10-15% throughout the entire spectral region investigated. For computing the value p' which is related to the value of the geometric albedo p by the following relationship:

$$p' = p\,\frac{\varphi(\Phi)}{\varphi(0)}, \tag{1}$$

we made use of the following formula:

$$p' = \frac{E_{♀}}{E_{\odot}} \cdot \frac{\Delta^2 r^2}{R^2}. \tag{2}$$

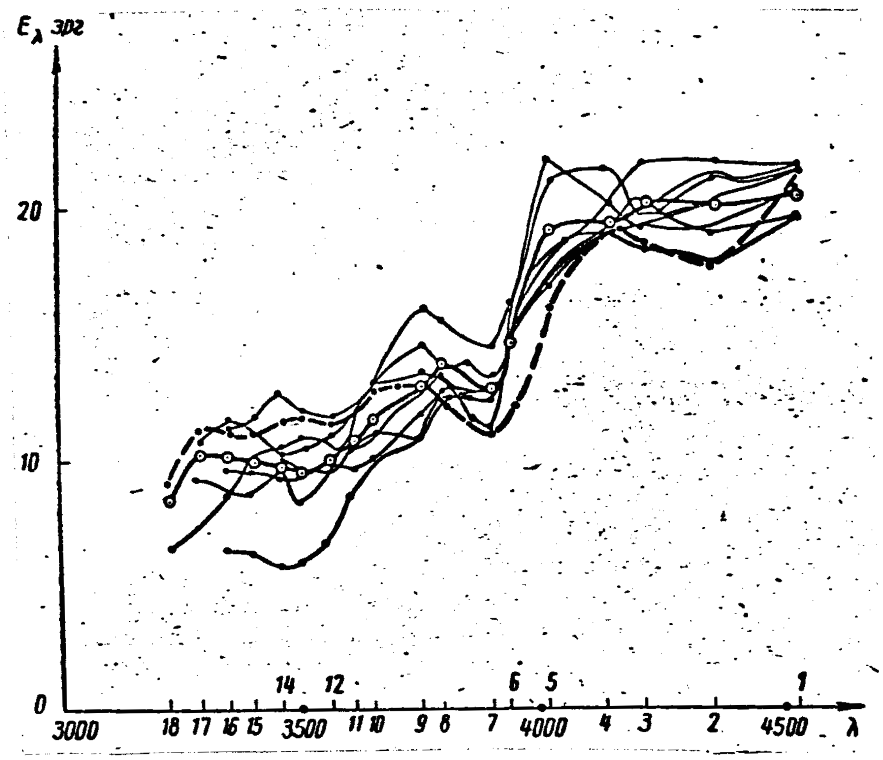

Fig. 1

In formula (2) $E_{\odot}$ and $E_{♀}$ represent the illumination produced by the sun and Venus, respectively, per square centimeter of earth's surface outside of the atmosphere; R is the radius of Venus in astronomic units; $\varphi(\Phi)$ and $\varphi(0)$ are the values of the phase function for the phase angle corresponding to the moment of observation and for $\Phi = 0$. The value R = 6,100 km, according to [3], was adopted as the radius of Venus.

For each night of observation computations were made for the value of log p'_λ. The mean values of this magnitude are given in Table 2. The error in determining log p'_λ is 10%.

E_* and $E_\odot$ are the monochromatic illumination of α Lyr and the sun, respectively, in erg/cm^2 with $\Delta\lambda = 1$ cm.

Since the observations embraced a small portion of the phase curve (angle Φ changed from 89° to 73°), it was impossible to make an extrapolation to the zero phase. Hence the ratio $\frac{\varphi(\Phi)}{\varphi(0)}$ was taken from the work by Knuckles, M. Sinton and V. Sinton [4] which contained the phase curves for Venus in the U, B, V system.

Since the effective wavelengths in the U, B, V system in the case of Venus are equal respectively to 3,530 Å, 4,480 Å, and 5,540 Å [5] it was possible for the 3,530 Å and 4,480 Å wavelengths to compute the magnitude of the geometric albedo ρ. Using the values of the phase integrals Qu and Q_B from [4], we found for the spherical albedo Å the value Å = 0.90 for λ = 4,480 Å, and Å = 0.76 for λ = 3,350 Å. These values are somewhat high even when compared with the values A = 0.78 for 4,480 Å and A = 0.53 for λ = 3,530 Å given in [4] which, in turn, are considerably higher than the results obtained by the preceding authors [4].

However, we should take into account the fact that there is a great deal of uncertainty in making an extrapolation for the zero phase. Thus, for the visual region (λ = 5,540 Å) according to the data in [4].

$$\frac{\varphi(0)}{\varphi(80^\circ)} = 4.8.$$

If we were to find the value of this relationship using the Danjon [6] phase curve we would get 3.2.

The magnitude A was also determined using the phase curve given in [6]. Since Danjon's observations pertain only to the visual region of the spectrum it was assumed that the rate of change of the phase integral from a long wave is the same as in [4]. Thence, using Danjon's phase curve we get the following values for the spherical albedo A: A = 0.745 for λ = 4,180 Å and A = 0.470 for λ = 3,530 Å; this is in considerably better agreement with the results of Knuckles, M. Sinton and V. Sinton. The rather wide divergences in albedo values offered by different authors are apparently related to the differences in methods of observation. However, the values A cited in [4], appear to be most plausible.

Shown as a solid line in Fig. 2 is the relationship of the albedo of Venus to the wave length. The albedo decreases slightly as the wavelength diminishes; the two minima are near λ = 3,500 Å and λ = 4,100 Å. In the interval 4,500 Å - 3,200 Å the albedo decreases to $0^m \cdot 3$.

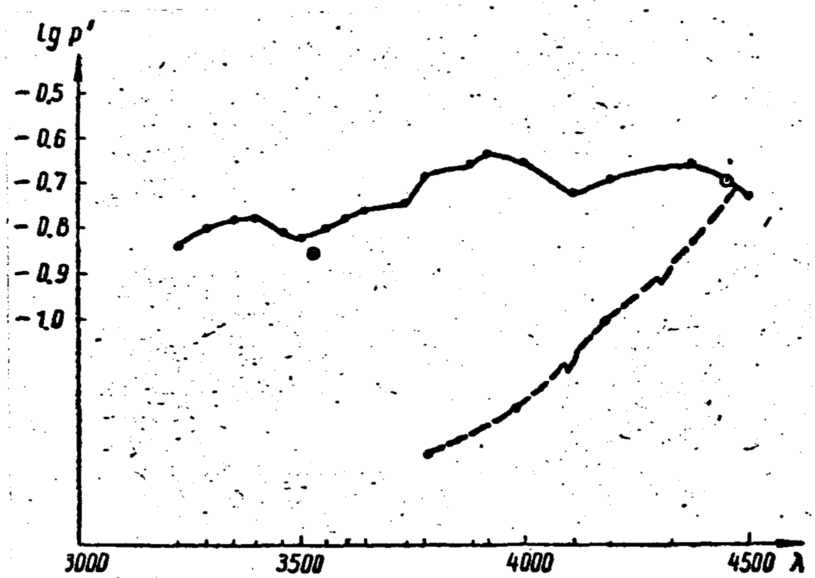

Fig. 2

Kozyrev [7] found that in the violet portion of the spectrum the albedo of Venus drops markedly; this drop is to $1^m \cdot 5$ in the interval λλ 4,500 Å - 3,800 Å, while in the 6,500 Å - 4,500 Å region the albedo drops by only a factor of 1.6. The curve showing the course of the albedo obtained by Kozyrev is shown as a broken line in Fig. 2.

The sharp drop of the albedo in wave lengths shorter than 4,500 Å is attributable by Kozyrev to absorption by an unknown multi-atomic organic molecule.

Either this conclusion by Kozyrev and the relationship he obtained of the albedo of Venus to the wave length are erroneous, or the content of this molecule in the atmosphere of Venus changes with time.

A possible reason for the appearance of errors is the great difference in the exposure made while photographing the spectra of Venus and the sun.

The relationship of the albedo of Venus to the wave length which we obtained is in good agreement with the results of photometric studies made of Venus in the U, B, V [4] system. Shown in Fig. 2 as small circles are the values of log A taken from [4] for $\lambda = 3{,}530$ Å and $\lambda = 4{,}480$ Å. (Zero point for the value of log A is matched with the zero point of our curve for $\lambda = 4{,}480$ Å).

Since the trend of the albedo in the visual region of the spectrum and in the ultraviolet region is the same (slight drop with a decrease in the wave length), scattering in the atmosphere of Venus in these areas of the spectrum is caused by the same agent.

In conclusion, I take the opportunity to thank T. V. Vodop'yanov for his assistance in processing the materials gathered in observations.

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